U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-266 139

Dissolved Oxygen, Temperature, Survival of Young at Fish Spawning Sites

Environmental Research Lab -Duluth, Minn

Prepared for

North Dakota State Univ, Fargo Dept of Zoology

Dec 76

PB 266 139

EPA-600/3-76-113
December 1976

Ecological Research Series

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/3-76-113		

4. TITLE AND SUBTITLE	5. REPORT DATE
Dissolved Oxygen, Temperature, Survival of Young at Fish Spawning Sites	December 1976 (Issuing Date)
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) John J. Peterka and James S. Kent	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Zoology North Dakota State University Fargo, North Dakota 58102	10. PROGRAM ELEMENT NO. 1BA608 11. CONTRACT/GRANT NO. R 801976
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Research Laboratory - Duluth, Minn. Office of Research and Development U.S. Environmental Protection Agency Duluth MN 55804	13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/03
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

Fluctuations of dissolved oxygen concentrations and water temperatures in their natural spawning sites were measured during embryo through larva stages of northern pike (Esox lucius), and during embryo and sac larva stages of bluegills (Lepomis macrochirus) and pumpkinseeds (Lepomis gibbosus). At northern pike sites, dissolved oxygen concentrations from combined measurements 1 and 10 cm from the bottom ranged from 0.0-16.6 mg/liter, and water temperatures from 2.5-23.0 C; average daily fluctuations were 3.0 mg/liter and 1.6 C. For bluegill and pumpkinseed nests, dissolved oxygen concentrations 1 cm from the bottom ranged from 2.4-18.2 mg/liter and water temperatures from 15.0-27.5 C, with average daily fluctuations of 4.4 mg/liter and 3.3 C. In field experiments to determine acute effects of a single exposure to low dissolved oxygen concentrations, tolerance decreased from embryo to larva stages for northern pike and from embryo to sac larva stages from bluegills and smallmouth bass (Micropterus dolomieui).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Dissolved gases, *Temperature, *Embryos, *Larvae, Bass, Fishes, Mortality, Fresh water, Bioassay	Dissolved oxygen, Fluctuations, Spawning, Esocidae, Centrarchidae, Natural habitat	06/F

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	46
	20. SECURITY CLASS (This page) Unclassified	22. PRICE PC A03 / MF A01

EPA Form 2220-1 (9-73)

U.S. GOVERNMENT PRINTING OFFICE: 1977-757-056/5504

EPA-600/3-76-113
December 1976

DISSOLVED OXYGEN, TEMPERATURE, SURVIVAL OF YOUNG AT FISH SPAWNING SITES

By

John J. Peterka
James S. Kent
Department of Zoology
North Dakota State University
Fargo, North Dakota 58102

Grant No. R801976

Project Officer
Richard Siefert
Environmental Research Laboratory
Duluth, Minnesota 55804

ENVIRONMENTAL RESEARCH LABORATORY--DULUTH
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
DULUTH, MINNESOTA 53804

DISCLAIMER

This report has been reviewed by the Environmental Research Laboratory - Duluth, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

Our nation's freshwaters are vital for all animals and plants, yet our diverse uses of water---for recreation, food, energy, transportation, and industry---physically and chemically alter lakes, rivers, and streams. Such alterations threaten terrestrial organisms, as well as those living in water. The Environmental Research Laboratory in Duluth, Minnesota develops methods, conducts laboratory and field studies, and extrapolates research findings

--to determine how physical and chemical pollution affects aquatic life

--to assess the effects of ecosystems on pollutants

--to predict effects of pollutants on large lakes through use of models

--to measure bioaccumulation of pollutants in aquatic organisms that are consumed by other animals, including man

This report provides measurements of fluctuations of dissolved oxygen and water temperature adjacent to embryos and sac larvae of northern pike, bluegills, and pumkinseeds in their natural spawning sites. It also describes field experiments designed to determine the effects of brief exposure of various concentrations of dissolved oxygen on early life stages of northern pike, bluegill, and smallmouth bass in their natural habitat.

Donald I. Mount, Ph. D.
Director
Environmental Research Laboratory
Duluth, Minnesota

ABSTRACT

Fluctuations of dissolved oxygen concentrations and water temperatures in their natural spawning sites were measured during embryo through larva stages of northern pike (Esox lucius), and during embryo and sac larva stages of bluegills (Lepomis macrochirus) and pumpkinseeds (Lepomis gibbosus). At northern pike sites, dissolved oxygen concentrations from combined measurements 1 and 10 cm from the bottom ranged from 0.0-16.6 mg/liter, and water temperatures from 2.5-23.0 C; average daily fluctuations were 3.0 mg/liter and 1.6 C. For bluegill and pumpkinseed nests, dissolved oxygen concentrations 1 cm from the bottom ranged from 2.4-18.2 mg/liter and water temperatures from 15.0-27.5 C, with average daily fluctuations of 4.4 mg/liter and 3.3 C. In field experiments to determine acute effects of a single exposure to low dissolved oxygen concentrations, tolerance decreased from embryo to larva stages for northern pike and from embryo to sac larva stages for bluegills and smallmouth bass (Micropterus dolomieui).

This report was submitted in fulfillment of Grant Number R801976, by the Department of Zoology, North Dakota State University, under the partial sponsorship of the Environmental Protection Agency. Work was completed August 1976.

CONTENTS

	Page
Foreword	iii
Abstract	iv
Figures	vi
Acknowledgments	vii
1. Introduction	1
2. Conclusions	2
3. Recommendations	3
4. Methods	4
5. Results	8
6. Discussion	20
References	
Appendices	
A. Dissolved Oxygen Concentrations and Water Temperatures in a Northern Pike Spawning Marsh	23
B. Dissolved Oxygen and Water Temperatures in Centrarchid Nests	26
C. Northern Pike Oxygen Tolerance Experiments	28
D. Centrarchid Oxygen Tolerance Experiments	31

FIGURES

No.		Page
1	Siphoning apparatus to collect water samples	5
2	Dissolved oxygen concentrations in a northern pike spawning marsh	9
3	Water temperatures in a northern pike spawning marsh	10
4	Water temperatures and dissolved oxygen concentrations measured 5 cm from the bottom by two Delta recorders in a northern pike spawning marsh	11
5	Mean water temperatures and dissolved oxygen concentrations 1 cm from the bottom in bluegill and pumpkinseed nests	14
6	Water temperatures and dissolved oxygen concentrations measured 5 cm from the bottom by two Delta recorders in bluegill spawning areas	15
7	Survival of northern pike embryos, sac larvae and larvae exposed for 8 h to various concentrations of dissolved oxygen	17
8	Survival of smallmouth bass and bluegill embryos and sac larvae exposed for 6 h and for 4 h, respectively, to various concentrations of dissolved oxygen	18

ACKNOWLEDGEMENTS

The authors thank the Minnesota Department of Natural Resources, Detroit Lakes Fish Hatchery for permitting us to conduct studies at Crane Lake and the spawning marsh at Silver Lake; the U.S. Fish and Wildlife Service for use of hatchery ponds at the Valley City National Fish Natchery; and both the above as well as the North Dakota Game and Fish Department, Spiritwood Lake Fish Hatchery for providing fish embryos and larvae.

SECTION 1

INTRODUCTION

In their extensive review of dissolved oxygen requirements for fishes, Doudoroff and Shumway (1) reported that the contradictory results in many of the studies could be lessened through controlled experiments in which natural conditions are closely simulated. Our purpose was to contribute to the design of such experiments at the Environmental Research Laboratory--Duluth, Minnesota by providing measurements of fluctuations of dissolved oxygen and water temperature adjacent to embryos and sac larvae of northern pike (Esox lucius), bluegills (Lepomis macrochirus), and pumpkinseeds (Lepomis gibbosus) in their natural spawning sites. We studied embryos and sac larvae because they are relatively immobile and therefore unable to avoid exposure to extremes, and because there is a lack of detailed information on dissolved oxygen concentrations and water temperatures encountered by these stages.

To assess how low dissolved oxygen concentrations observed in the field influenced hatching success and survival we conducted field experiments with embryos, sac larvae, and larvae of northern pike, and embryos and sac larvae of bluegills and smallmouth bass (Micropterus dolomieui). Except for the brief exposure times to various levels of dissolved oxygen, all fish were kept in their natural surroundings where they were exposed to fluctuating environmental factors; differences in survival from controls were then attributed to effects of dissolved oxygen concentrations used in the treatments.

SECTION 2

CONCLUSIONS

In a northern pike spawning marsh, average dissolved oxygen concentrations and water temperatures measured at combined depths of 1 and 10 cm from the bottom, increased from morning to afternoon, respectively: 4.8 to 8.1 mg/liter and 6.1 to 7.3 C during the embryo stage, 3.3 to 6.6 mg/liter and 8.3 to 10.3 C during the sac larva stage, and 2.8 to 5.3 mg/liter and 8.2 to 9.8 C during the larva (free swimming) stage. Dissolved oxygen concentrations 1 and 10 cm from the bottom were 1.0 mg/liter and less in 7% of the measurements made during embryo stages and in 18% of the measurements during sac larva stages; their maximum duration was 10 h in a 24 h period.

In bluegill and pumpkinseed nests, average dissolved oxygen concentrations and water temperatures 1 cm from the bottom during embryo through sac larva stages increased from morning to afternoon and were, respectively, 7.1 to 11.5 mg/liter and 20.0 to 23.3 C; values measured at 10 cm from the bottom and at the surface were similar. Dissolved oxygen concentrations during embryo through larva stages were 4.0 mg/liter or less on only 5 of 53 days; supersaturation occurred in the afternoons on 48 of 53 days. The presence of males guarding the nests did not appear to affect oxygen levels; oxygen concentrations adjacent to the nests were similar to those inside.

For all species tested, tolerance to low dissolved oxygen concentrations decreased from embryo to larva stages. While northern pike embryos exposed for 8 h to 0.6 mg/liter survived as well as controls, larvae required concentrations of 2.0 mg/liter and greater, and exposure for only 2 h to 0.8 mg/liter drastically reduced their survival. Larvae exposed for 8 h required oxygen concentrations of 4.0 mg/liter and greater. For smallmouth bass exposed for 6 h, embryo hatching success at 1.0 mg/liter and greater and sac larva survival at 2.2 mg/liter and greater was similar to controls. Compared with controls, bluegill embryos exposed for 4 h tolerated concentrations as low as 0.5 mg/liter, and sac larvae tolerated levels as low as 1.8 mg/liter; survival of sac larvae was drastically reduced by exposure for 2 h to 0.5 mg/liter of dissolved oxygen.

SECTION 3

RECOMMENDATIONS

Because marked stratification of dissolved oxygen concentrations and water temperatures occurred in spawning sites of northern pike, we found it necessary to take samples manually at depths near and just above the bottom to represent conditions to which embryos and sac larvae were exposed; marked stratification was not found in bluegill or pumpkinseed nests. We found 20 ml water samples for dissolved oxygen determinations were the smallest we could take and still retain accuracy. Delta dissolved oxygen recorders provided useful information regarding daily and seasonal trends and durations of extremes, but we did not find them consistent enough to provide accurate measurements. The continuous movement of water caused by the stirring mechanism affected micro-stratification.

It is feasible to use field-based experiments to determine effects of dissolved oxygen concentrations on survival of early life-stages of northern pike, bluegills and smallmouth bass. However, we found it difficult to maintain fish from embryo to early feeding stages. Future experiments should be designed to provide a minimum handling of fish, particularly during daily counts, in order to minimize shock.

SECTION 4

METHODS

DISSOLVED OXYGEN AND WATER TEMPERATURE

Dissolved oxygen and water temperatures were measured in a northern pike spawning marsh, Silver Lake, Clay County, and in bluegill and pumpkinseed nests, Crane Lake, Ottertail County, Minnesota. Northern pike were studied from mid-April, when spawning began, until mid-May when fry were observed, 1974 and 1975. Adult northern pike were stocked and marsh water levels were controlled by fisheries personnel of the Minnesota Department of Natural Resources. For bluegills and pumpkinseeds, dissolved oxygen and water temperatures were measured from the time a nest was first seen until the male fish abandoned the nest. Measurements were made from early June until mid-July, 1973 and 1974.

In 1973, we determined, from samples collected every 2 h for several days in Crane Lake, that lows of dissolved oxygen occurred at 0800-0900 (CDST) and highs at 1600-1700. We confirmed these times both there and in the Silver Lake marsh in 1974 with continuous records of dissolved oxygen concentrations. Daily samples were taken during these periods to provide measurements of extremes in dissolved oxygen concentrations. Dissolved oxygen was measured from water samples collected at the surface with a van Dorn sampler and from those siphoned 1 and 10 cm from the bottom through Tygon tubing (inside diameter of .24 cm) into 20 ml glass-stoppered weighing bottles. To develop siphons, we placed sample bottles in a weighted plastic pail to allow the bottles and tips of siphon tubes to be lowered below the water's surface [Magnuson (2)] (Fig. 1). Sampling depths of 1 cm from the bottom were chosen to represent dissolved oxygen concentrations adjacent to embryos and larvae of northern pike on the bottom; those at 10 cm to represent conditions adjacent to embryos and sac larvae on vegetation above the bottom.

At each depth duplicate samples were prepared by thoroughly flushing the siphon tubes and replacing the volume of the sampling bottles at least twice. Samples were fixed using the azide modification of the Winkler method [A.P.H.A. (3)]. Chemicals for fixing the 20 ml samples were used in reduced volumes (0.1 ml); 8.2 ml of fixed sample was titrated with 0.002 N $Na_2S_2O_3$ in a buret with graduations of 0.05 ml. Dissolved oxygen was measured to the nearest 0.1 mg/liter. Where discrepancies greater than 0.3 mg/liter between duplicate samples occurred, a third titration was run using the mixed remainders of the two samples; means were determined from the closest two out of three measurements. To provide a check on the accuracy of dissolved

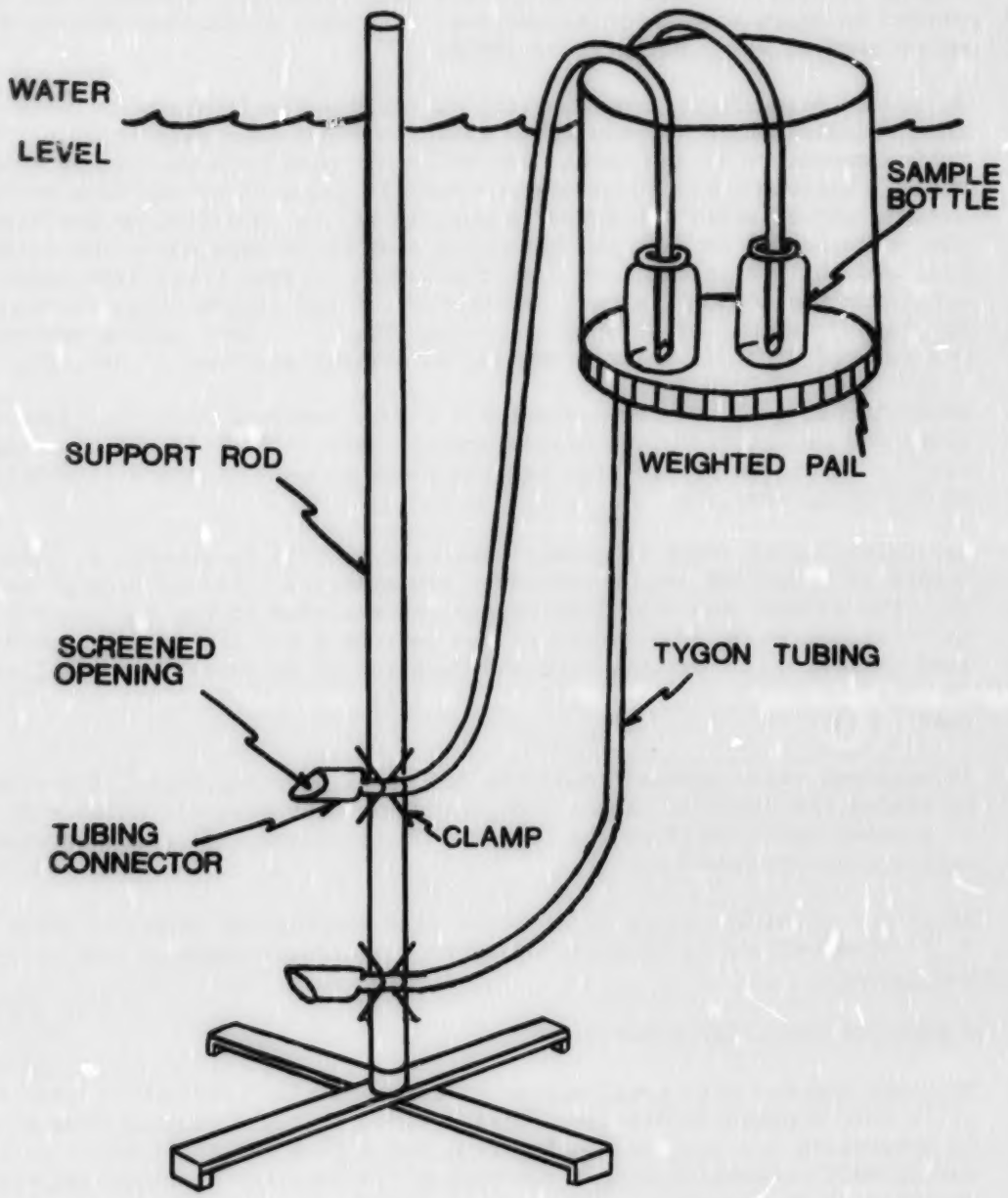

Figure 1. Siphoning apparatus to collect water samples.

oxygen determinations in small samples, duplicate macro samples (200 ml) and small samples (8.2 ml) were prepared from water collected at the surface. Any differences of dissolved oxygen in macro and small samples were used to adjust dissolved oxygen values for all small samples, assuming the dissolved oxygen in macro samples to be correct. The mean difference between duplicate macro samples was 0.03 mg/liter (N=30).

To reduce disturbance from sampling of any dissolved oxygen or water temperature stratification, siphon tubes extended 1-2 m from each station. A tubing connector at the intake end of each siphon tube was cut at a 45° angle. Because tests in laboratory aquaria using methylene blue crystals as tracers showed water was drawn to the tip of the connector we positioned the connector 10 cm from the bottom to draw water from above the connector tip, and the connectors 1 cm from the bottom to draw water from below the connector tip to help prevent disturbance of any oxygen stratification due to slight currents created by siphoning (Fig. 1). Each tubing connector-end was covered with 316μ Nitex netting to prevent entrance of detritus.

Water temperatures to the nearest 0.5 C were measured with thermistors at times and depths dissolved oxygen samples were collected. As with siphon tubes, thermistor probes were left in place to prevent any disturbance of water during sampling.

Two Delta (Model 3610) recorders were used in 1974 to provide a continuous record of dissolved oxygen and water temperatures. Probes were placed 5 cm from the bottom, and dissolved oxygen was recorded to the nearest 0.2 mg/liter and water temperature to the nearest 1 C. The meters provided a good indication of daily trends and duration of extremes, but problems with the need for frequent calibration led us to discontinue their use after one year.

We measured water movement near the bottom of spawning sites of northern pike by timing the drift of plumes from methylene blue crystals which were dropped on a metal grid placed on the bottom. Observations of the plumes were made with a glass-bottomed pail.

Durations of early stages of northern pike development were estimated from field observations of hatching of embryos and development of sac larvae and larvae.

OXYGEN TOLERANCE EXPERIMENTS

In field experiments, early stages of northern pike, smallmouth bass and bluegills were exposed to dissolved oxygen concentrations ranging from no oxygen to saturation for periods ranging from 1-8 h (8 h was the longest period during which dissolved oxygen concentrations measured remained below 1.0 mg/liter in the northern pike spawning marsh).

Northern pike, obtained from the National Fish Hatchery, Valley City, N.D. and from N.D. State Hatchery, Spiritwood, ranged from 1-day-old embryos to larvae. Smallmouth bass embryos and sac larvae were obtained from nests in

spawning ponds at the National Fish Hatchery, Valley City. Bluegill embryos and sac larvae were obtained from nests at Crane Lake, Minnesota.

Chambers containing embryos, sac larvae or larvae were returned to natural surroundings following each treatment where they were elevated on racks to prevent disturbance of the bottom and avoid siltation. Survival was measured daily by counting live and dead fish in the chambers. For experiments with embryos, survival was recorded until hatching was complete. Survival of sac larvae and larvae was recorded until most in control chambers died. Northern pike embryos were treated in solutions of 1:600 formalin for 16 min about every two days (method used at the National Fish Hatchery, Valley City, N.D.) when fungused embryos were observed. Fungus was not a problem with centrarchids because of short incubation periods.

Chambers were constructed of PVC pipe with an inside diameter of 4.3 cm and a length of 2.3 cm with covers of 316μ opening Nitex netting. To permit development of northern pike sac larvae to the feeding stage where any delayed exposure effects could be observed, we used large holding chambers constructed of 13.2 liter (3 gal) and 22.0 liter (5 gal) polyethylene tubs with openings covered with 750μ Nitex netting.

During treatment, chambers were placed in 22.0 liter polyethylene buckets filled with lake water in which dissolved oxygen was controlled by bubbling various mixtures of compressed nitrogen and air. The buckets were kept in the lake to maintain natural temperatures. Gas mixtures were adjusted by flow meters and a gas manifold. Dissolved oxygen and water temperatures were recorded at about 1 h intervals during the experiments. The change in pH due to bubbling nitrogen gas in the northern pike marsh water was from 8.5 to 8.7 at a concentration of 0.3 mg/liter of dissolved oxygen; the pH of water in Crane Lake changed from 8.4 to 8.9 at a concentration of 0.3 mg/liter dissolved oxygen. We did not consider these changes in pH to affect survival of fish.

Analysis of variance with replications and with treatments fixed was used in the experiments. When zero values occurred, 1.0 was added to each value for computation of sums of squares. Duncan's Multiple Range Test was used to determine significant differences among means [Steel and Torrie (3)].

SECTION 5

RESULTS

DISSOLVED OXYGEN AND WATER TEMPERATURE--NORTHERN PIKE

Dissolved oxygen in 1974 and 1975 generally was lowest at 1 cm from the bottom and highest at the surface. Dissolved oxygen concentrations were lower in the morning than in the afternoon at all water depths measured, and decreased at a given depth from embryo to larva stages (Fig. 2; Appendix A, Table 1). Daily fluctuations in dissolved oxygen and differences between morning and afternoon measurements during the embryo and sac larva stages were less in 1975 than in 1974.

Dissolved oxygen concentrations at all depths fluctuated markedly from day to day and from morning to afternoon (Fig. 2). The maximum day-to-day decreases in 1974 were from 14.7 to 3.8 and from 10.2 to 2.7 mg/liter at 10 and 1 cm from the bottom, respectively, from the afternoon of 26 April to the afternoon of 27 April. In 1975, a decrease at 10 cm from 9.8 to 6.2 mg/liter and at 1 cm from 6.5 to 2.9 mg/liter from the afternoon of 6 May to the afternoon of 7 May was the largest measured. The greatest differences between morning and afternoon concentrations on the same day were 3.5 to 15.0 mg/liter at 1 cm on 23 April 1974, and 3.2 to 9.4 mg/liter at 10 cm on 5 May 1975.

Mean dissolved oxygen concentrations measured 5 cm from the bottom with Delta oxygen recorders at two stations from 23 April to 12 May 1974, were lowest at 0800-0900 and highest at 1600-1700 CDST (Fig. 4). Because daily patterns of dissolved oxygen fluctuations were similar, we chose 2 days to illustrate data from continuous recordings: 24 April, when highest concentrations of dissolved oxygen occurred, and 28 April, when lowest concentrations occurred (Fig. 4). Dissolved oxygen was 0.0 mg/liter for 6 h on 28 April and was less than 0.6 mg/liter for 8 h. We observed that oxygen increased slightly before and then decreased at sunrise on 8 mornings from 27 April-13 May at one of the recorders and on 6 mornings from 24 April-8 May at the other recorder (Fig. 4). The weather from 24 April-13 May was windy and cloudy with much rain which could have caused the pre-sunrise increases of dissolved oxygen. Dissolved oxygen concentrations measured by the recorders were similar to averages of manual measurements made 10 cm from the bottom. Means of dissolved oxygen determined with recorders for embryos, sac larvae, and larvae, respectively, were 7.4, 6.5, and 5.5 mg/liter; those for manual measurements were 7.6, 6.0, and 5.1 mg/liter (Appendix A, Table 1).

Average daily water temperatures generally increased from April to May in 1975, whereas in 1974 they remained rather uniform (Fig. 3). Water

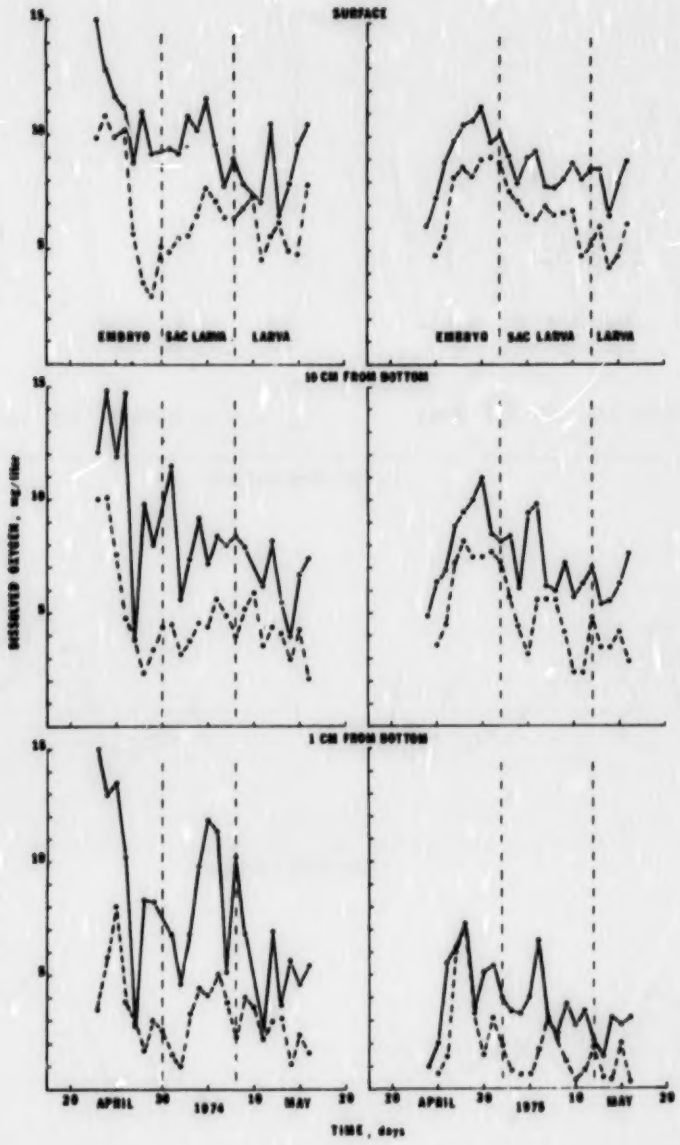

Figure 2. Dissolved oxygen concentrations in a northern pike spawning marsh. Each point represents the mean determined from measurements at two stations at the surface, and at 10 and 1 cm from the bottom. Broken line represents measurements at 0800-0900 (CDST), and solid line represents measurements at 1600-1700.

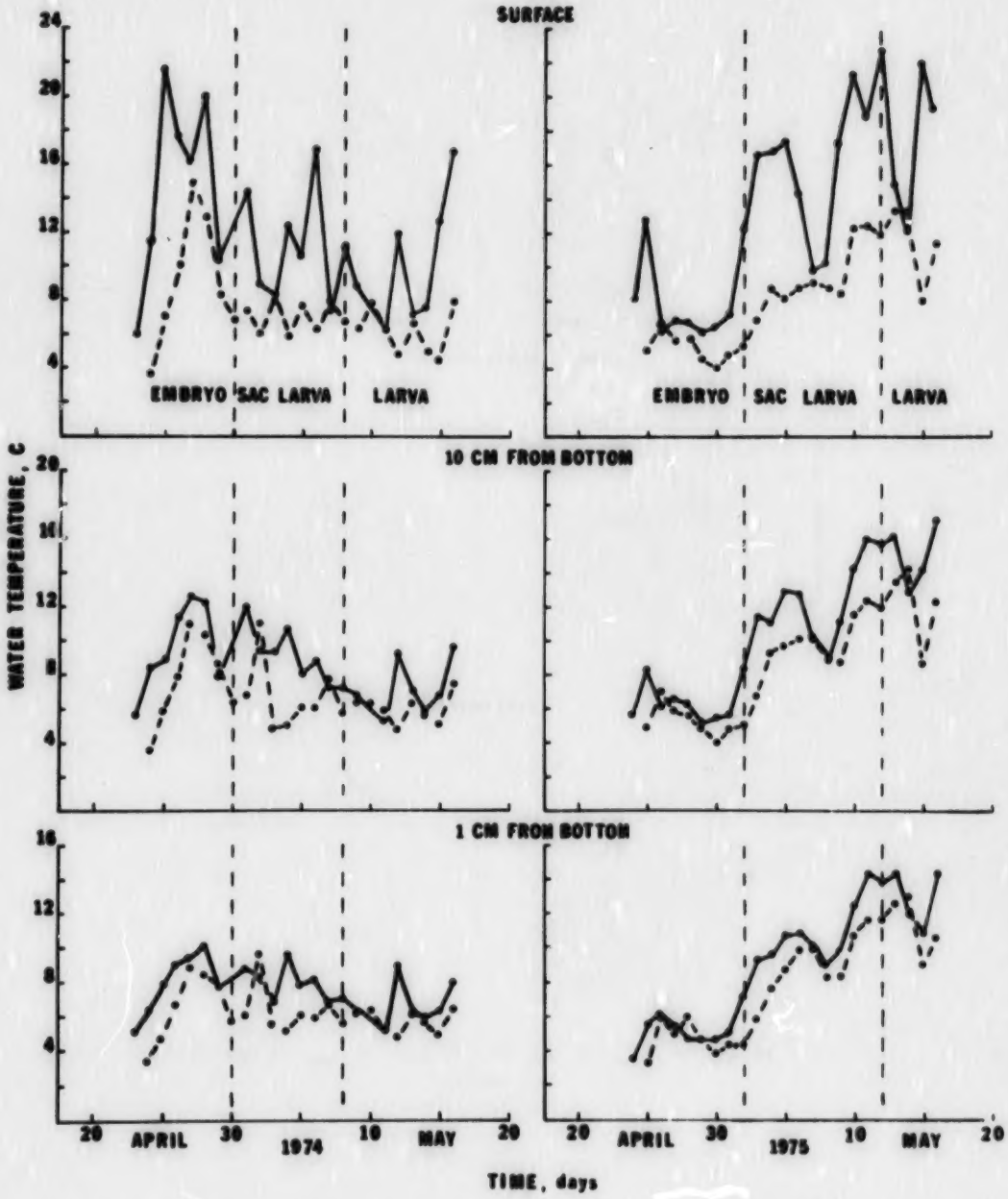

Figure 3. Water temperatures in a northern pike spawning marsh. Each point represents the mean determined from measurements at two stations at the surface, and at 10 and 1 cm from the bottom. Broken line represents measurements at 0800-0900 (CDST), and solid line represents measurements at 1600-1700.

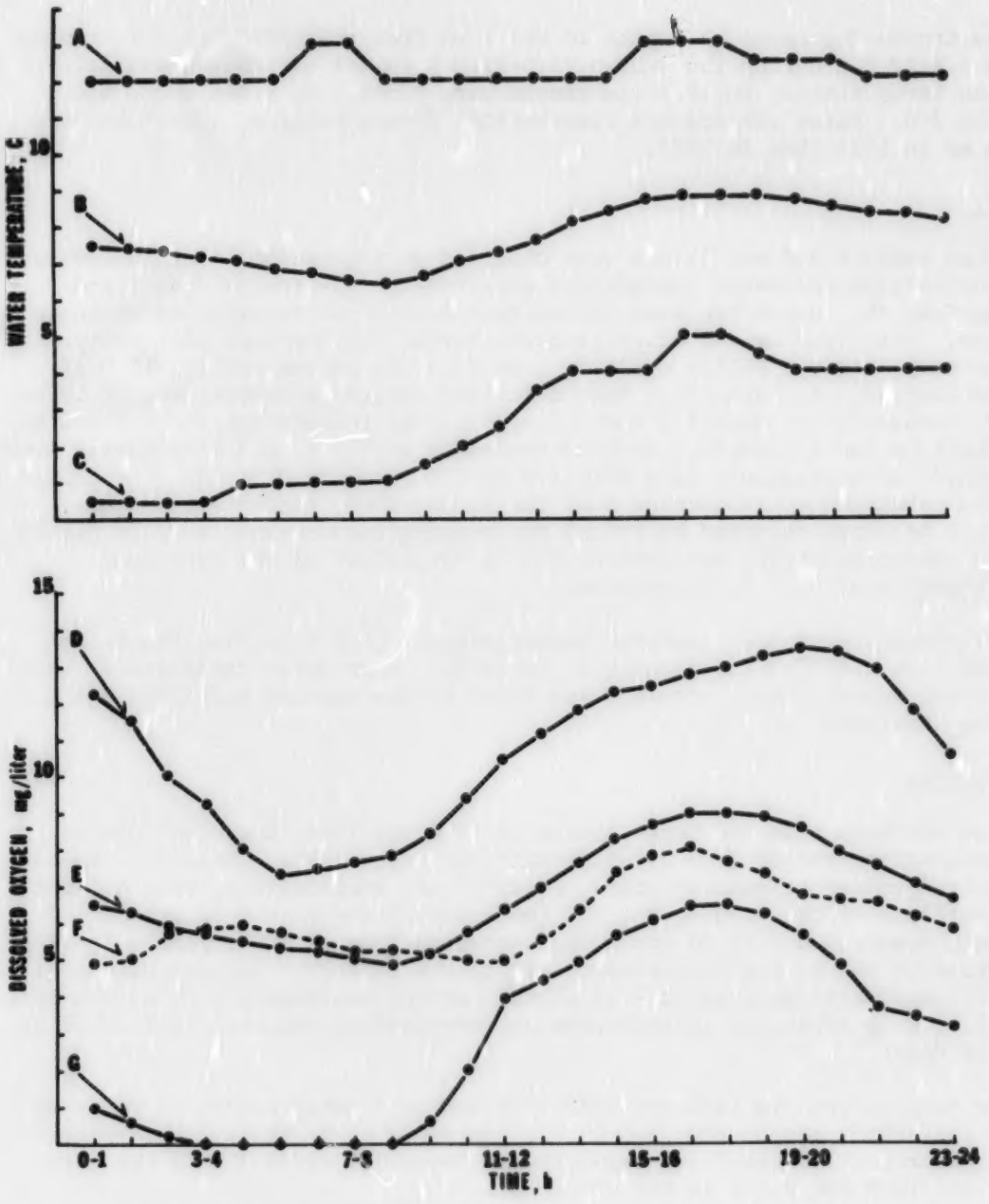

Figure 4. Water temperatures and dissolved oxygen concentrations measured 5 cm from the bottom by two Delta recorders in a northern pike spawning marsh. A.-28 April 1974, day of highest water temperature. B.-Average water temperature from 23 April-12 May 1974. C.-23 April 1974, day of lowest water temperature. D.-24 April 1974, day of highest dissolved oxygen. E.-Average dissolved oxygen from 23 April-12 May 1974. F.-Average dissolved oxygen from 1-4 May 1974, indicating an increase in dissolved oxygen before sunrise, followed by a decrease at sunrise. G.-28 April 1974, date of lowest dissolved oxygen.

temperatures for combined depths 10 and 1 cm from the bottom in 1974 ranged from 3.5-12.8 C during the embryo, 5.0-11.2 C in the sac larva, and 5.0-9.0 C in the larva stages; in 1975 the ranges were 3.5-8.5 C, 6.2-14.5 C, and 8.8-16.2 C. Water temperature fluctuations from morning to afternoon were greater in 1974 than in 1975.

Embryo

Because embryos and sac larvae were observed on vegetation, dissolved oxygen concentrations and water temperature measured in 1974 and 1975 at 1 and 10 cm from the bottom are used to describe conditions experienced by these stages. Dissolved oxygen concentrations during the northern pike embryo stage ranged from 0.3-16.6 mg/liter 1 cm from the bottom and 1.2-15.0 at 10 cm (Appendix A, Table 1). Mean dissolved oxygen concentrations at 10 and 1 cm, respectively, were 6.0 and 3.5 mg/liter in the morning and 9.3 and 6.9 mg/liter in the afternoon. When measurements at the 10 and 1 cm levels were combined, concentrations less than 1.0 mg/liter occurred in 10% (6 out of 60) of the morning measurements or 5 of the 15 mornings; concentrations of 1.1-2.0 mg/liter occurred in 18% of the morning measurements or 7 of the 15 days. Supersaturation occurred in 14% (9 out of 64) of the afternoon measurements or 6 of 16 afternoons.

Water temperatures from combined measurements 10 and 1 cm from the bottom ranged from 2.5-16.0 C (Appendix A, Table 2). Mean water temperatures at 10 and 1 cm, respectively, were 6.5 and 5.6 C in the morning and 8.0 and 6.6 C in the afternoon.

Sac Larvae

During northern pike sac larva stages in 1974 and 1975, dissolved oxygen concentrations ranged from 0.0-13.4 mg/liter (Appendix A, Table 1). Mean dissolved oxygen concentrations at 10 and 1 cm, respectively, were 4.4 and 2.2 mg/liter in the morning and 7.6 and 5.6 mg/liter in the afternoon. Of 74 morning measurements at 10 and 1 cm, concentrations of 1.0 mg/liter and less occurred in 24% of the measurements (13 of the 18 days); concentrations of 1.1-2.0 mg/liter occurred in 9.5% of the morning measurements (9 of the 18 days). Of 72 afternoon measurements supersaturation occurred in 9.8% (6 of the 18 days).

Water temperatures in 1974 and 1975 from combined measurements 10 and 1 cm from the bottom ranged from 4.0-17.0 C (Appendix A, Table 2). Mean water temperatures at 10 and 1 cm, respectively, were 8.5 and 8.0 C in the mornings and 10.9 and 9.7 C in the afternoons.

Larvae

In 1974 and 1975, dissolved oxygen concentrations ranged from 0.0 at 1 cm from the bottom to 12.0 mg/liter at the surface (Appendix A, Table 1). Mean dissolved oxygen concentrations at 10 and 1 cm, respectively, were 3.8 and 1.9 mg/liter in the morning and 6.4 and 4.2 mg/liter in the afternoon; at the surface means were 5.8 (morning) and 8.3 mg/liter (afternoon). Although concentrations of 2.0 mg/liter and less occurred in 25% of the morning

measurements, mostly at 1 cm from the bottom, higher oxygen concentrations were present at other depths.

Water temperatures ranged from 4.0-22.5 C (Appendix A, Table 2). Mean water temperatures for the three depths ranged from 8.0-8.3 C in the mornings and from 9.1-13.2 C in the afternoons.

DISSOLVED OXYGEN AND WATER TEMPERATURE--CENTRARCHIDS

In general, dissolved oxygen concentrations and water temperatures measured in nests of bluegills and pumpkinseeds in 1973 and 1974 were higher at a given depth in the afternoon than in the morning; measurements taken at the surface in water depths of about 0.7 m differed only 0.6 mg/liter and 0.4 C from measurements taken 1 cm from the bottom (Appendix B), and daily fluctuations and mean values were similar in both years (Fig. 5).

Because, unlike the northern pike studied, embryos and sac larvae were found only at the bottom, and because no stratification occurred we will limit our discussion here to measurements 1 cm from the bottom. The mean dissolved oxygen concentration 1 cm from the bottom was 7.1 mg/liter in the morning and 11.5 mg/liter in the afternoon with a range of 2.4-18.2 mg/liter (Appendix B, Table 1). In spite of this large range, 71% of the morning measurements were 6.1-9.0 mg/liter and 61% of the afternoon measurements were 9.1-13.0 mg/liter. Supersaturation occurred on 18 of 53 mornings and on 48 of 53 afternoons. The low of 2.4 mg/liter of dissolved oxygen was measured in one pumpkinseed nest found in very shallow water of 0.3 m. Both maximum and minimum dissolved oxygen concentrations were recorded at stations on the lee side of the lake. Mean water temperatures at 1 cm from the bottom were 20.0 C in the morning and 23.3 C in the afternoon with a range of 15.0-27.5 C (Appendix B, Table 2).

Mean dissolved oxygen concentrations measured 5 cm from the bottom with Delta recorders at 2 stations from 9 June to 5 July 1974, were lowest at 0800-0900 and highest at 1700-1800 CDST (Fig. 6). The lowest dissolved oxygen concentration, 5.0 mg/liter, was recorded on 21 June, and highest, 16.0 mg/liter, on 26 June.

To determine if nest-guarding activities of male fish affected dissolved oxygen levels, we measured dissolved oxygen with manual methods in 8 nests and 1 m outside each of these nests in 1974. Average dissolved oxygen concentrations 1 cm from the bottom were 7.5 mg/liter inside the nests (mornings); this was not significantly different ($P < .01$, $N = 43$) from 7.2 mg/liter outside the nests. Means of the afternoon measurements were 11.9 mg/liter ($N = 39$) both inside and outside the nests.

OXYGEN TOLERANCE EXPERIMENTS--NORTHERN PIKE

Embryo

A 77% hatching success occurred with embryos exposed for 8 h on the 7th day after fertilization to dissolved oxygen of 0.6 mg/liter, which was similar to hatching success of 80-93% in the higher concentrations tested (Fig. 7;

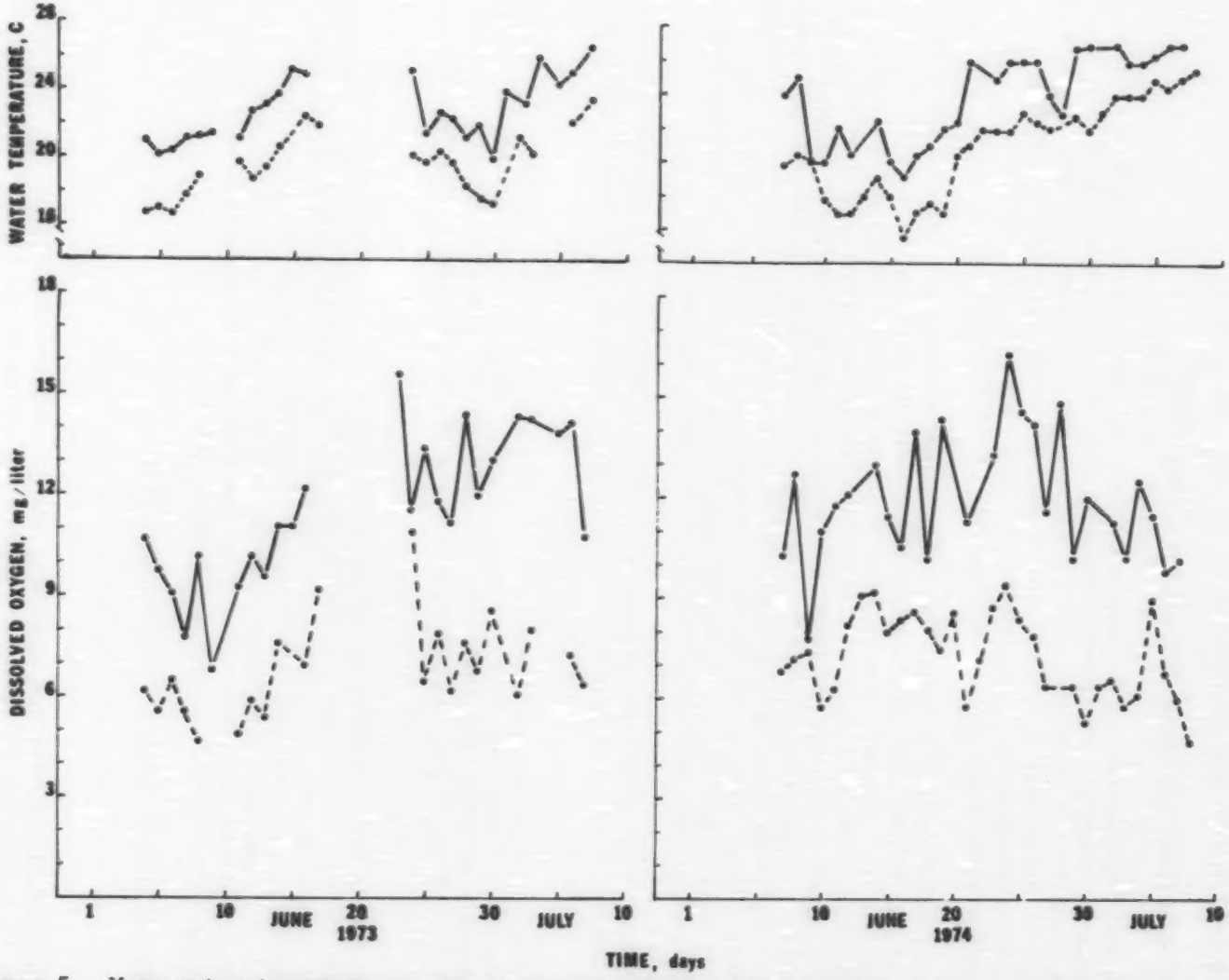

Figure 5. Mean water temperatures and dissolved oxygen concentrations 1 cm from the bottom in bluegill and pumpkinseed nests. Broken line represents measurements at 0800-0900 (CDST), and solid line represents measurements at 1600-1700. Each point represents the mean determined from 1-3 nests.

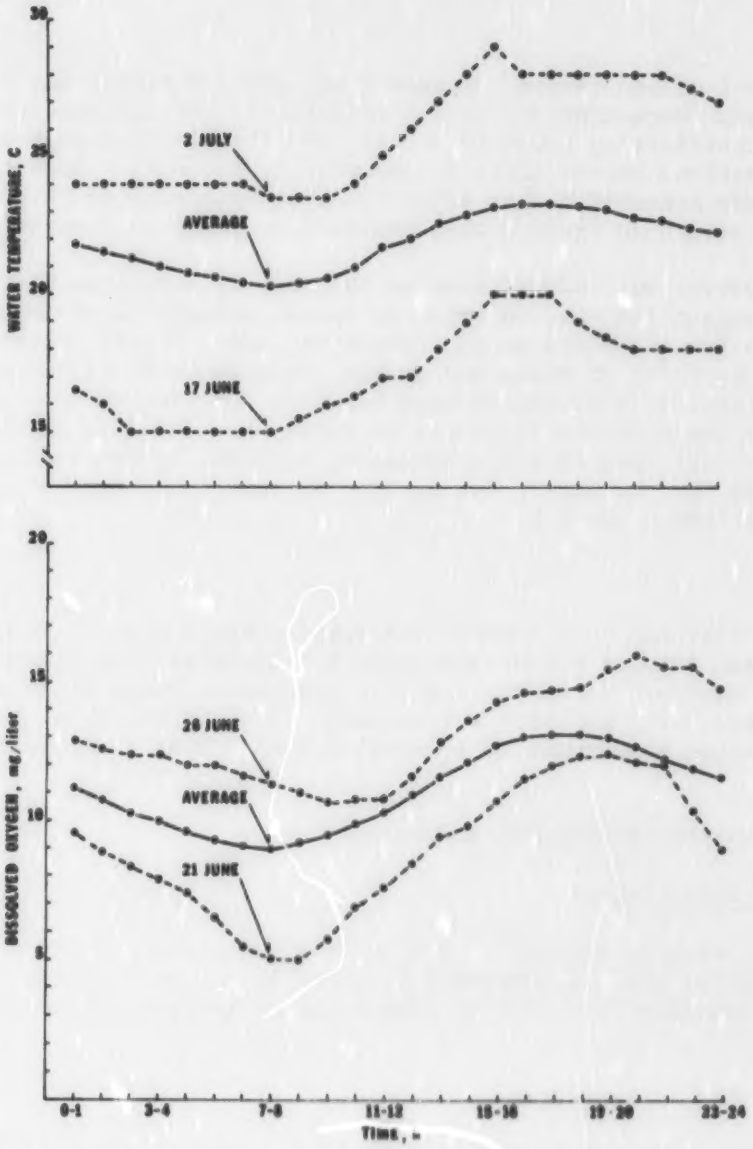

Figure 6. Water temperatures and dissolved oxygen concentrations measured 5 cm from the bottom by two Delta recorders in bluegill spawning areas from 9 June-5 July, 1974. Broken lines represent days of highest and lowest temperatures and dissolved oxygen concentrations.

Appendix C, Table 1). Hatching began 10 days after fertilization; all embryos had hatched by the 12th day following fertilization.

Sac Larvae

Mean survival of sac larvae, exposed 1 day after hatching for 8 h to dissolved oxygen concentrations of 0.3 mg/liter in two experiments was 51%. This was significantly lower ($P < .01$) than the 87-97% survival in the higher concentrations tested (Fig. 7; Appendix C, Table 2). Mean total lengths of sac larvae measured 8 days after hatching were similar ($P < .05$) in the first experiment; no lengths were measured in the second experiment.

Because survival was reduced when we exposed sac larvae to 0.3 mg/liter of dissolved oxygen for 8 h, we tried to assess effects of various durations of exposure to low dissolved oxygen concentrations. No sac larvae treated 3 days after hatching in dissolved oxygen concentrations of 0.8 mg/liter survived exposure for 6 h, 6% survived for 4 h, 14% survived for 2 h, and 88% survived in the controls (Appendix C, Table 3). Survival in the controls was higher ($P < .01$) than in all treatments; survival in the treatments was not different at the .01 level, but at the .05 level, survival after 2 h exposure was greater than after 6 h.

Larvae

All larvae that had just reached the feeding stage died after 8 h in dissolved oxygen concentrations averaging 1.6 mg/liter (Fig.7; Appendix C, Table 4). Survival in controls and in treatments where dissolved oxygen ranged from 3.5-9.3 mg/liter was 93-100%. High mortality of larvae in controls prevented assessment of survival for more than 1 day following treatment.

OXYGEN TOLERANCE EXPERIMENTS--CENTRARCHIDS

Smallmouth Bass--Embryo

Two-day-old embryos exposed to 0.5 mg/liter of dissolved oxygen for 6 h died before hatching (Fig. 8; Appendix D, Table 1). Mean hatching success of 69-91% was similar ($P < .01$) in higher concentrations tested of 1.8-7.9 mg/liter.

Smallmouth Bass--Sac Larvae

No sac larvae survived at a dissolved oxygen concentration of 0.5 mg/liter when treated 1 day after hatching for 6 h (Fig. 8; Appendix D, Table 2). Mean survival of 53-83% was similar ($P < .01$) in the higher concentrations tested of 2.2-9.0 mg/liter. In another experiment, survival of sac larvae treated with dissolved oxygen levels of 1.0-2.0 mg/liter for 6 h was 85%; this was not significantly different ($P < .01$) from the 95% survival in controls.

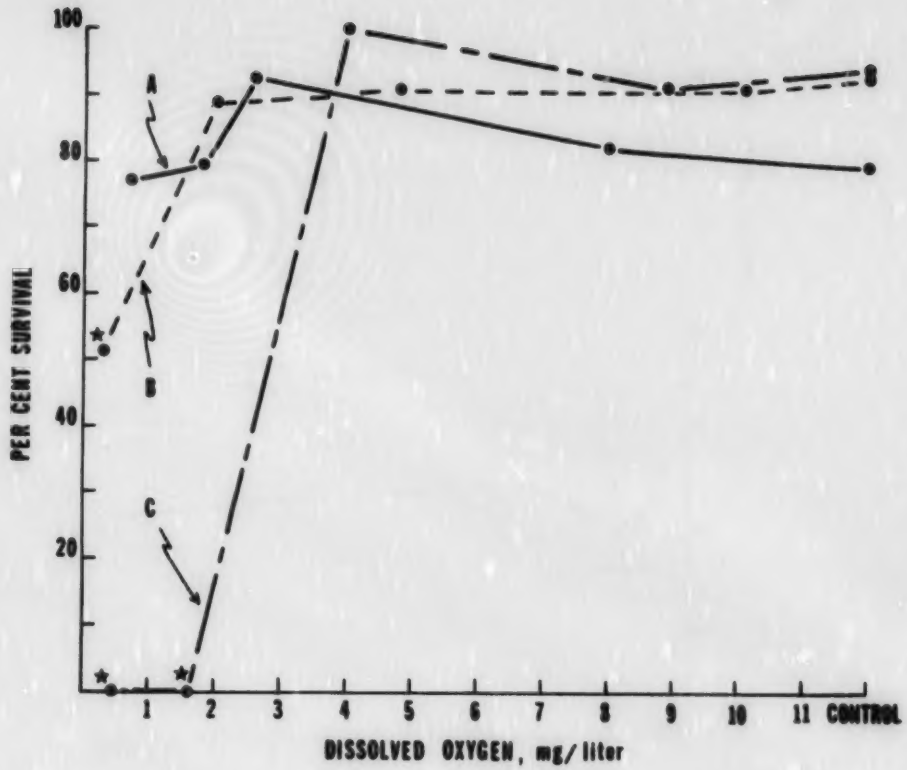

Figure 7. Survival of northern pike embryos, sac larvae and larvae exposed for 8 h to various concentrations of dissolved oxygen. A. -Hatching success of embryos exposed 7 days after fertilization. B.-Survival of sac larvae exposed 1 day after hatching. C.-Survival of larvae exposed in early feeding stage. Stars indicate significant differences from controls. Detailed information found in Appendix C.

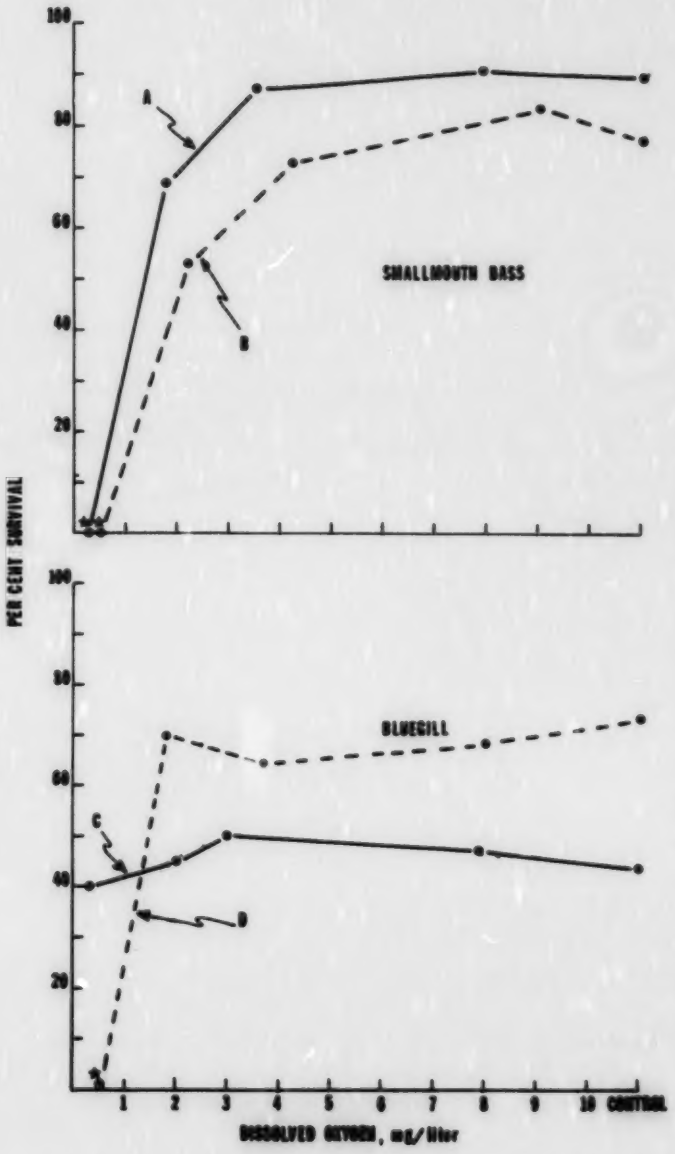

Figure 8. Survival of smallmouth bass and bluegill embryos and sac larvae exposed for 6 h and for 4 h, respectively, to various concentrations of dissolved oxygen. A.-Hatching success of smallmouth bass embryos exposed 2 days after fertilization. B.-Survival of smallmouth bass sac larvae exposed 1 day after hatching. C.-hatching success of bluegill embryos exposed 1 day after fertilization. D.-Survival of bluegill sac larvae exposed 1-4 days after fertilization. Stars indicate significant differences from controls. Detailed information in Appendix D.

Bluegill--Embryo

Mean hatching success of embryos, exposed for 4 h in two experiments to 0.5 mg/liter of dissolved oxygen was 40%; this was not significantly different ($P < .05$) from 44-50% hatched in concentrations of 2.1-7.8 mg/liter (Fig. 8; Appendix D, Table 3).

Bluegill--Sac Larvae

In four out of five experiments no sac larvae, 1-4 days after hatching, survived when exposed for 4 to 6 h to a dissolved oxygen concentration of 0.5 mg/liter. Mean survival ranged from 65-74% in the higher concentrations tested of 1.8-8.0 mg/liter (Fig. 8, Appendix D, Table 4). Exposure for 6 h rather than 4 h in one experiment did not reduce survival, which in this experiment was second highest of the five experiments. In concentrations of more than 1.8 mg/liter of dissolved oxygen, mean survival in water temperature of 26 C was 89% and was significantly higher ($P < .01$) than the mean survival of 56% in water temperature of 21-22 C. Mean survival of sac larvae exposed to dissolved oxygen concentrations of 0.5 mg/liter for periods ranging from 1-4 h was 0, 1, 11% for the 4, 3, 2 h exposures, respectively, and was lower ($P < .01$) than the 71, 79% survival in the 1 h exposure and in the control (Appendix D, Table 5). Although there was a significant interaction between experiments and treatments, this was probably due to the low survival of the controls in one of the five experiments. When this experiment is eliminated from the analysis, the interaction was non-significant.

SECTION 6

DISCUSSION

DISSOLVED OXYGEN AND WATER TEMPERATURE

Northern Pike

We measured dissolved oxygen concentrations and water temperatures in a northern pike spawning site during 2 years of extremely different weather conditions. In 1974 warm water temperatures during spawning were followed by cooler temperatures, and there were extreme day-to-day and morning-to-afternoon fluctuations of dissolved oxygen concentrations and water temperature. In 1975 there was a gradual warming trend from spawning to larva stages, and fluctuations of temperature and of dissolved oxygen were less than in 1974. In both years dissolved oxygen concentrations decreased from embryo to larva stages. The decrease was probably due to decomposition of grasses that had grown when the marsh bottom was dry during the preceding summer and fall.

Natural reproduction was measured from counts of numbers and wet weights of fingerlings released to Silver Lake when the marsh was drained in the summer (Detroit Lakes Fish Hatchery, Minnesota Department of Natural Resources). Estimated numbers of fingerlings resulting from 12 to 15 female northern pike in 1974 and 1975, respectively, were 3190 and 2500; the average wet weights were 1.6 and 2.7 g. The estimate for 1975 is believed to be low because large flows of water over the retaining wall dam during the spring permitted fingerlings to escape before the census was taken.

The two stations where manual measurements were taken had different exposures to wind, sunlight, and water currents which affected dissolved oxygen concentrations and water temperatures. Station A was sheltered from the wind and shaded in the afternoon by trees and cattails; water currents near the bottom on a calm day were 0.05 cm/sec. Station B was exposed to wind and afternoon sunlight; located near the main channel draining the marsh, its water current was 0.23 cm/sec. The faster movement of water at Station B was probably the reason the mean dissolved oxygen concentration at that station, 5.6 mg/liter, was greater than the 4.9 mg/liter mean at Station A. Both means are of measurements at combined depths 1 and 10 cm from the bottom. Exposure to afternoon sunlight was responsible for warmer average water temperatures from the combined depths 1 and 10 cm from the bottom of 9.0 C at Station B compared to 7.5 C at Station A. The faster water currents and afternoon sunlight also caused the frost to leave the bottom muds of Station B sooner than at Station A.

Centrarchids

In Crane Lake, where centrarchids were studied, dissolved oxygen concentrations and water temperatures during the spawning seasons 1974 and 1975 were similar and were characterized by low day-to-day fluctuations, little stratification with depth, and generally high concentrations of dissolved oxygen; supersaturation occurred on 90% of the days sampled. Lows of less than 4.0 mg/liter of dissolved oxygen were found on 10% of the mornings. We found dissolved oxygen concentrations on cloudy days to be lower than on clear days, but there were too few cloudy days to make statistical comparisons. No differences were found in dissolved oxygen inside and outside of bluegill nests guarded by male fish.

OXYGEN TOLERANCE EXPERIMENTS

For 8 h exposures to various levels of dissolved oxygen, survival was similar to that in the controls for northern pike embryos treated at concentrations of 0.6 mg/liter, for sac larvae treated at concentrations of 2.0 mg/liter and greater, and for larvae treated at concentrations of 4.0 mg/liter and greater. Apparently, tolerance to low dissolved oxygen concentrations decreases from embryo to larva stages. Even the age of sac larvae influenced tolerance to low dissolved oxygen concentration as no 3-day-old sac larvae survived a 6 h exposure to a concentration of 0.8 mg/liter, whereas 51% of 1-day-old sac larvae survived an 8 h exposure at 0.3 mg/liter. Survival of 3-day-old sac larvae was drastically reduced by exposure to 0.5 mg/liter of dissolved oxygen for only 2 h.

Siefert, Spoor, and Syrett (5) found that constant exposure to dissolved oxygen concentrations of about 5.0 mg/liter would permit good survival of northern pike from the embryo state through first feeding of larvae. Because of short exposure times to low dissolved oxygen concentrations used in our experiments, it is difficult to make comparisons with results from other studies. However, during embryo through larva stages, dissolved oxygen concentrations at combined depths 1 and 10 cm from the bottom were less than 5.0 mg/liter in 70% of the morning measurements and in 30% of the afternoon measurements indicating that naturally-occurring dissolved oxygen concentrations are frequently lower than concentrations reported necessary for good survival determined from laboratory experiments.

Hatching success of smallmouth bass embryos exposed for 6 h at concentrations of 1.0 mg/liter and greater of dissolved oxygen was similar to controls, as was survival of smallmouth bass sac larvae treated at 2.2 mg/liter and greater. Smallmouth bass embryos died when exposed to 0.5 mg/liter for 6 h. Siefert, Carlson, and Herman (6) found that after constant exposure of smallmouth bass embryos and larvae to various levels of dissolved oxygen, hatching took place at 2.5 mg/liter but death occurred by the fifth day of exposure; embryos treated with 1.2 mg/liter failed to hatch.

Hatching success of bluegill embryos exposed for 4 h at concentrations of 0.5 mg/liter was similar to controls; for sac larvae, survival was similar to controls at 1.5 mg/liter and greater. Survival of bluegills sac larvae was severely reduced by exposure to 0.5 mg/liter of dissolved oxygen for only 2 h.

REFERENCES

1. Doudoroff, P. and D. L. Shumway. Dissolved Oxygen Requirements of Freshwater Fishes. Food and Agriculture Organization of the United Nations, Rome, Italy. Technical Paper Number 86. 1970. 291 p.

2. Magnuson, J. J. and W. E. Stuntz. A Siphon Water Sampler for Use Through the Ice. Limnol. Oceanogr. 15:156-158, January 1970.

3. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, New York. 1971. p. 477-481.

4. Steel, R. G. D. and J. H. Torrie. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc., New York. 1960. p. 132-156.

5. Siefert, R. E., W. A. Spoor, and R. F. Syrett. Effects of Reduced Oxygen Concentrations on Northern Pike (Esox lucius) Embryos and Larvae. J. Fish. Res. Board Can. 30:849-852, June 1973.

6. Siefert, R. E., A. R. Carlson, and L. J. Herman. Effects of Reduced Oxygen Concentrations on the Early Life Stages of Mountain Whitefish, Smallmouth Bass, and White Bass. Prog. Fish Cult. 36 (4):186-190, October 1974.

APPENDIX A

DISSOLVED OXYGEN CONCENTRATIONS AND WATER TEMPERATURES IN A NORTHERN PIKE SPAWNING MARSH DURING THE EMBRYO, SAC LARVA, AND LARVA STAGES

MEASUREMENTS TAKEN AT 0800-0900 AND AT 1600-1700 CDST AT THE SURFACE AND AT 10 AND 1 cm FROM THE BOTTOM AT 2 STATIONS IN 1974 AND 1975. MEAN WATER DEPTHS WERE 0.5 m AND RANGED FROM 0.46 TO 0.58 m.

TABLE A-1. DISSOLVED OXYGEN CONCENTRATIONS (mg/liter) IN A NORTHERN PIKE SPAWNING MARSH DURING THE EMBRYO, SAC LARVA, AND LARVA STAGES, AND THE FREQUENCY AT WHICH VARIOUS DISSOLVED OXYGEN CONCENTRATIONS OCCURRED

Dissolved Oxygen								
	Embryo							
	Morning				Afternoon			
Depth	No.[a]	Average	S.D.	Range	No.[b]	Average	S.D.	Range
Surface	30	7.4	2.58	2.4-12.4	32	10.3	2.23	5.6-15.8
10	30	6.0	2.76	1.2-10.4	32	9.3	3.24	8.5-15.0
1	30	3.5	2.65	0.3- 9.6	32	6.9	4.62	0.8-16.6
Total	90	5.6	3.08	0.3-12.4	96	8.9	3.75	0.8-16.6
	Sac Larva							
Surface	37[c]	6.4	0.96	3.3- 8.2	36[d]	9.1	1.21	7.4-13.1
10	37	4.4	1.56	1.3- 7.4	36	7.6	2.17	2.8-12.6
1	37	2.2	2.03	0.0- 7.0	36	5.6	3.65	0.6-13.4
Total	111	4.3	2.33	0.0- 8.0	108	7.4	2.91	0.6-13.4
	Larva							
Surface	23[e]	5.8	1.24	3.6- 8.4	22[f]	8.3	1.74	5.5-12.0
10	23	3.8	1.62	1.0- 6.8	22	6.4	1.63	2.9- 9.1
1	23	1.9	1.56	0.0- 4.8	22	4.2	2.34	1.0-11.0
Total	69	3.8	2.14	0.0- 8.4	66	6.3	2.56	1.0-12.0

(continued)

APPENDIX A - TABLE A-1 (continued).

Frequency of Dissolved Oxygen in the Marsh

Dissolved Oxygen (mg/liter)	Morning						Afternoon					
	Embryo		Sac Larva		Larva		Embryo		Sac Larva		Larva	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.0- 1.0	6	6.7	18	16.2	10	14.5	1	1.0	2	1.9	0	0
1.1- 2.0	11	12.2	7	6.3	7	10.1	4	4.2	4	3.7	3	4.5
2.1- 3.0	4	4.4	9	8.1	6	8.7	5	5.2	6	5.6	6	9.1
3.1- 4.0	7	7.8	12	10.8	10	14.5	2	2.1	3	2.8	4	6.1
4.1- 5.0	10	11.1	10	9.0	16	23.2	1	1.0	6	5.6	6	9.1
5.1- 6.0	11	12.2	20	18.0	9	13.0	6	6.3	11	10.2	10	15.2
6.1- 7.0	8	8.9	27	24.3	7	10.1	9	9.4	9	8.3	12	18.2
7.1- 8.0	7	7.8	7	6.3	3	4.3	9	9.4	12	11.1	7	10.6
8.1- 9.0	11	12.2	1	0.9	1	1.4	6	6.3	19	17.6	11	16.7
9.1-10.0	11	12.2	0	0	0	0	17	17.7	20	18.5	3	4.5
10.1-11.0	2	2.2	0	0	0	0	12	12.5	10	9.3	1	1.5
11.1-12.0	1	1.1	0	0	0	0	7	7.3	2	1.9	3	4.5
12.1-13.0	1	1.1	0	0	0	0	3	3.1	2	1.9	0	0
13.1-14.0	0	0	0	0	0	0	3	3.1	2	1.9	0	0
14.1-15.0	0	0	0	0	0	0	7	7.3	0	0	0	0
15.1-16.0	0	0	0	0	0	0	3	3.1	0	0	0	0
16.1-17.0	0	0	0	0	0	0	1	1.0	0	0	0	0
Totals	90	100	111	100	69	100	96	100	108	100	66	100

[a]7 mornings from 23-30 April in 1974 and 8 mornings from 25 April - 2 May in 1975.

[b]8 afternoons from 23-30 April in 1974 and 8 afternoons from 24 April - 1 May in 1975.

[c]8 mornings from 1-8 May in 1974 and 10 mornings from 3-12 May in 1975.

[d]8 afternoons from 1-8 May in 1974 and 10 afternoons from 2-12 May in 1975.

[e]7 mornings from 9-16 May in 1974 and 4 mornings from 13-16 May in 1975.

[f]6 afternoons from 9-16 May in 1974 and 4 afternoons from 13-16 May in 1975.

APPENDIX A (continued)

TABLE A-2. WATER TEMPERATURES (C) IN A NORTHERN PIKE SPAWNING MARSH DURING THE EMBRYO, SAC LARVA, AND LARVA STAGES

Water Temperatures								
	Morning				Afternoon			
Depth	No.	Average	S.D.	Range	No.	Average	S.D.	Range
Embryo								
Surface	30	7.2	3.21	3.5-15.0	32	11.1	5.27	5.0-22.0
10	30	6.5	2.46	3.5-14.0	32	8.0	2.94	4.7-16.0
1	30	5.6	2.22	2.5-12.0	32	6.6	2.65	3.5-14.0
Total	90	6.4	2.71	2.5-15.0	96	8.6	4.22	3.5-22.0
Sac Larva								
Surface	37	8.8	2.29	5.0-13.0	36	14.4	4.46	7.0-23.0
10	37	8.5	2.38	5.0-12.5	36	10.9	3.04	6.0-17.0
1	37	8.0	2.39	4.0-12.5	36	9.7	2.50	5.0-15.0
Total	111	8.4	2.36	4.0-13.0	108	11.7	3.95	5.0-23.0
Larva								
Surface	23	8.2	3.14	4.0-14.0	22	13.2	5.39	6.0-22.5
10	23	8.3	3.36	5.0-14.5	22	10.0	4.18	5.0-17.5
1	23	8.0	3.08	5.0-14.0	22	9.1	3.39	5.0-15.0
Total	69	8.2	3.15	4.0-14.5	66	10.8	4.68	5.0-22.5

APPENDIX B

DISSOLVED OXYGEN CONCENTRATIONS AND WATER TEMPERATURES IN CENTRARCHID NESTS DURING EARLY-LIFE STAGES

MEASUREMENTS TAKEN AT 0800-0900 AND AT 1600-1700 CDST AT THE SURFACE AND AT 10 and 1 cm FROM THE BOTTOM AT UP TO 3 STATIONS IN 1973 AND 1974. MEAN WATER DEPTHS WERE 0.7 m AND RANGED FROM 0.27 TO 1.07 m.

TABLE B-1. DISSOLVED OXYGEN CONCENTRATIONS (mg/liter) IN BLUEGILL AND PUMPKINSEED NESTS DURING EMBRYO AND SAC LARVA STAGES, AND THE FREQUENCY AT WHICH VARIOUS DISSOLVED OXYGEN CONCENTRATIONS OCCURRED

Dissolved Oxygen

	Morning				Afternoon			
Depth	No.	Average	S.D.	Range	No.	Average	S.D.	Range
Surface	145[a]	7.7	1.31	4.8-13.2	144[b]	12.1	1.76	7.1-16.5
10	145	7.5	1.35	4.6-13.5	144	12.2	1.99	6.8-19.2
1	145	7.1	1.57	2.4-12.6	144	11.5	2.53	4.8-18.2
Total	435	7.5	1.43	2.4-13.5	432	12.0	2.13	4.8-19.2

Frequency of Dissolved Oxygen

Dissolved Oxygen (mg/liter)	Morning				Afternoon			
	1 cm		Total		1 cm		Total	
	No.	%	No.	%	No.	%	No.	%
2.1- 3.0	2	1.4	2	0.5	0	0	0	0
3.1- 4.0	3	2.1	3	0.7	0	0	0	0
4.1- 5.0	8	5.5	12	2.8	3	2.1	3	0.7
5.1- 6.0	17	11.7	43	9.9	2	1.4	2	0.5
6.1- 7.0	39	26.9	109	25.1	3	2.1	5	1.2
7.1- 8.0	34	23.4	111	25.5	1	0.7	3	0.7
8.1- 9.0	30	20.7	109	25.1	5	3.5	12	2.8
9.1-10.0	8	5.5	32	7.3	16	11.1	34	7.9
10.1-11.0	2	1.4	8	1.8	25	17.4	74	17.1
11.1-12.0	1	0.7	3	0.7	28	19.4	95	22.0
12.1-13.0	1	0.7	1	0.2	20	13.9	75	17.4
13.1-14.0	0	0	2	0.5	13	9.0	59	13.7
14.1-15.0	0	0	0	0	17	11.8	40	9.3

(continued)

APPENDIX B - TABLE B-1 (continued)

Frequency of Dissolved Oxygen

Dissolved Oxygen (mg/liter)	Morning				Afternoon			
	1 cm		Total		1 cm		Total	
	No.	%	No.	%	No.	%	No.	%
15.1-16.0	0	0	0	0	7	4.9	18	4.2
16.1-17.0	0	0	0	0	1	0.7	6	1.4
17.1-18.0	0	0	0	0	2	1.4	4	0.9
18.1-19.0	0	0	0	0	1	0.7	1	0.2
19.1-20.0	0	0	0	0	0	0	1	0.2
Sum	145	100	435	100	144	100	432	100

[a]22 mornings from 4 June to 5 July in 1973 and 31 mornings from 7 June to 8 July in 1974.

[b]25 afternoons from 4 June to 5 July in 1973 and 28 afternoons from 7 June to 8 July in 1974.

TABLE B-2. WATER TEMPERATURES (C) IN BLUEGILL AND PUMPKINSEED NESTS DURING EMBRYO AND SAC LARVA STAGES

Water Temperature

Depth	Morning				Afternoon			
	No.	Average	S.D.	Range	No.	Average	S.D.	Range
Surface	145	19.7	2.60	14.0-25.0	144	23.7	2.73	18.0-29.0
10	145	20.0	2.59	15.0-26.5	144	23.3	2.42	18.5-27.5
1	145	20.0	2.54	15.0-25.5	144	23.3	2.44	18.5-27.5
Total	435	19.9	2.58	14.0-26.5	432	23.4	2.53	18.0-29.0

APPENDIX C

RESULTS OF NORTHERN PIKE OXYGEN TOLERANCE EXPERIMENTS

TABLE C-1. HATCHING SUCCESS OF NORTHERN PIKE EMBRYOS EXPOSED 7 DAYS AFTER FERTILIZATION FOR 8 h AT 10 C TO DISSOLVED OXYGEN CONCENTRATIONS LISTED Fifteen Embryos Initially in Each Chamber. Exposures Made on 7 May, and Survival Recorded 5 Days Later.

Average Dissolved Oxygen (mg/liter)	0.6	1.8	2.6	8.0	Control
Range of Dissolved Oxygen (mg/liter)	0.5-0.7	1.0-2.0	2.5-4.5	7.0-9.5	Control
Percent Survival	77	80	93	83	80
Days to First Hatch	10	10	10	10	10
Days to 90% Hatch	11	11	11	11	11

Analysis of Variance

sov	df	ss	ms	F
Treatment	4	14.800	3.700	1.542 N.S.
Error	15	36.000	2.400	
Total	19	50.800		

TABLE C-2. SURVIVAL OF NORTHERN PIKE SAC LARVAE EXPOSED 1 DAY AFTER HATCHING FOR 8 h AT 8-11 C TO DISSOLVED OXYGEN CONCENTRATIONS LISTED Fifteen Sac Larvae Initially in Each Chamber. In Two Experiments Survival Recorded 8 and 4 Days After Treatment.

Duncan's Multiple Range Test[a]

Average Dissolved Oxygen (mg/liter)	0.3	2.0	Control	4.8	10.1	Control
Range of Dissolved Oxygen (mg/liter)	0.2-0.5	1.5-2.0	Control	3.0-6.5	9.0-11.0	Control
Average Length (mm)	10.63	10.85	10.73	10.87	10.83	10.73
Percent Survival[b]	51	87	91	91	92	97
.05	—					
.01	—					

(continued)

APPENDIX C - TABLE C-2 (continued).

Analysis of variance[c]

sov	df	ss	ms	F
Subgroups	11	219.417	19.417	
Treatments	5	192.917	38.583	10.445*
Experiment	1	8.028	8.028	1.428 N.S.
Interaction	5	18.472	3.649	0.657 N.S.
Error	23	129.333	5.623	
Total	34	348.750		

[a]Underlined values not different at 0.05 and 0.01 levels.

[b]Percentages given are for combined survival rates of two experiments.

[c]Because of zero readings, 1 was added to all values for computation of ss.

TABLE C-3. SURVIVAL OF NORTHERN PIKE SAC LARVAE EXPOSED 3 DAYS AFTER HATCHING AT 12-13 C TO LOW DISSOLVED OXYGEN CONCENTRATIONS OF 0.8 mg/liter FOR TIMES LISTED
Fifty Sac Larvae Initially in Each Chamber. Treatment Given on 14 May, and Survival Recorded 3 Days Later.

Duncan's Multiple Range Test[a]

Exposure Time	6 h	4 h	2 h	Control
Percent Survival	0	6	14	88
.05				—
.01				—

Analysis of Variance[b]

sov	df	ss	ms	F
Treatment	3	2530	843.333	187.407**
Error	4	18	4.500	
Total	7	2548		

[a]Underlined values not different at 0.05 and 0.01 levels.

[b]Because of zero readings, 1 was added to all values for computation of ss.

(continued)

APPENDIX C (continued)

TABLE C-4. SURVIVAL OF NORTHERN PIKE LARVAE, EXPOSED AT EARLY FEEDING STAGE FOR 8 h AT 10-14 C TO DISSOLVED OXYGEN CONCENTRATIONS LISTED Ten Larvae Initially in Each Chamber. Treatment Given on 20 May and Survival Recorded 1 Day Later.

Duncan's Multiple Range Test[a]

Average Dissolved Oxygen (mg/liter)	0.5	1.6	8.9	Control	Control	4.0
Range of Dissolved Oxygen (mg/liter)	0.5	1.0-2.0	8.2-9.3	Control	Control	3.5-4.5
Percent Survival	0	0	93	93	97	100
.05	_____		_____			
.01	_____		_____			

Analysis of Variance[b]

sov	df	ss	ms	F
Treatments	5	368.278	73.656	441.885**
Error	12	2.000	0.129	
Total	17	370.278		

[a]Underlined values not different at 0.05 and 0.01 levels.

[b]Because of zero readings, 1 was added to all values for computation of ss.

APPENDIX D

RESULTS OF CENTRARCHID OXYGEN TOLERANCE EXPERIMENTS

TABLE D-1. HATCHING SUCCESS OF SMALLMOUTH BASS EMBRYOS EXPOSED 2 DAYS AFTER FERTILIZATION FOR 6 h AT 20-23 C TO DISSOLVED OXYGEN CONCENTRATIONS LISTED
Fifteen Embryos Initially in Each Chamber. Treatment Given in Two Experiments, and Survival Recorded When Hatching was Complete.

Duncan's Multiple Range Test[a]

Average Dissolved Oxygen (mg/liter)	0.5	1.8	3.5	Control	7.9
Range of Dissolved Oxygen (mg/liter)	0.5	1.0-2.0	3.0-5.0	Control	7.5-9.0
Percent Survival[b]	0	69	87	89	91
.05	___	_____	_____	_____	_____
.01	___	_____	_____	_____	_____

Analysis of Variance[c]

sov	df	ss	ms	F
Subgroups	9	976.326	108.408	
Treatments	4	943.314	235.829	57.967**
Experiment	1	14.860	14.860	3.118 N.S.
Interaction	4	18.152	4.538	.952 N.S.
Error	24	114.377	4.766	
Total	33	1090.703		

[a]Underlined values not different at 0.05 and 0.01 levels.

[b]Percentages given are for combined survival rates of two experiments.

[c]Because of zero readings, 1 was added to all values for computation of ss.

(continued)

APPENDIX D (continued)

TABLE D-2. SURVIVAL OF SMALLMOUTH BASS SAC LARVAE EXPOSED 1 DAY AFTER HATCHING FOR 6 h AT 17 C TO DISSOLVED OXYGEN CONCENTRATIONS LISTED Ten Sac Larvae Initially in Each Chamber. Treatment Given on 30 May, and Survival Recorded 2 Days Later.

Duncan's Multiple Range Test[a]

Average Dissolved Oxygen (mg/liter)	0.5	2.2	4.2	Control	9.0
Range of Dissolved Oxygen (mg/liter)	0.3-0.6	2.0-2.5	3.5-4.5	Control	8.5-9.5
Percent Survival	0	53	73	77	83
.05	—				
.01	—				

Analysis of Variance[b]

sov	df	ss	ms	F
Treatments	4	138.267	34.567	7.103**
Error	10	48.666	4.867	
Total	14	186.933		

[a]Underlined values not different at 0.05 and 0.01 levels.

[b]Because of zero readings, 1 was added to all values for computation of ss.

(continued)

APPENDIX D (continued)

TABLE D-3. HATCHING SUCCESS OF BLUEGILL EMBRYOS EXPOSED 1 DAY AFTER FERTILIZATION FOR 4 h AT 25-28 C TO DISSOLVED OXYGEN CONCENTRATIONS LISTED
Fifteen Embryos Initially in Each Chamber. Survival Recorded 1 Day After Treatment When Hatching was Complete.

Average Dissolved Oxygen (mg/liter)	0.5	2.1	3.0	7.8	Control
Range of Dissolved Oxygen (mg/liter)	0.5	1.5-2.5	2.5-3.5	7.5-9.5	Control
Percent Survival[a]	40	46	50	47	44

Analysis of Variance

SOV	df	ss	ms	F
Subgroups	9	20.700	4.140	
Treatments	4	7.533	1.883	0.824 N.S.
Experiments	1	4.033	4.033	1.491 N.S.
Interaction	4	9.134	2.284	0.845 N.S.
Error	18	48.667	2.704	
Total	27	69.367		

[a]Percentages given are for combined survival rates of two experiments.

(continued)

APPENDIX D (continued)

TABLE D-4. SURVIVAL OF BLUEGILL SAC LARVAE EXPOSED 1-4 DAYS AFTER HATCHING FOR 4 h AT 21-26 C TO DISSOLVED OXYGEN CONCENTRATIONS LISTED Ten Sac Larvae Initially in Each Chamber. Survival Recorded 1 Day After Treatment in Five Experiments.

Duncan's Multiple Range Test[a]

Average Dissolved Oxygen (mg/liter)	0.5	3.7	8.0	1.8	Control
Range of Dissolved Oxygen (mg/liter)	0.5	2.5-4.5	7.4-9.0	1.5-2.5	Control
Percent Survival[b]	1	65	69	70	74
.05					
.01					

Analysis of Variance[c]

sov	df	ss	ms	F
Subgroups	24	707.187	29.466	
Treatments	4	561.587	140.397	33.224**
Experiments	4	77.987	19.487	6.131**
Interaction	16	67.613	4.226	1.329 N.S.
Error	49	155.833	3.180	
Total	73	863.020		

[a]Underlined values not different at 0.05 and 0.01 levels.

[b]Percentages given are for combined survival rates of five experiments.

[c]Because of zero readings, 1 was added to all values for computation of ss.

(continued)

APPENDIX D (continued)

TABLE D-5. SURVIVAL OF BLUEGILL SAC LARVAE EXPOSED 1-4 DAYS AFTER HATCHING AT 23-28 C TO LOW DISSOLVED OXYGEN CONCENTRATIONS OF 0.5 mg/liter FOR TIMES LISTED
Ten Sac Larvae Initially in Each Chamber. Survival Recorded 1 Day After Treatment in Five Experiments.

Duncan's Multiple Range Test[a]

Treatment Time	4 h	3 h	2 h	1 h	Control
Percent Survival[b]	0	1	11	71	79
.05					
.01					

Analysis of Variance[c]

sov	df	ss	ms	F
Subgroups	24	1001.013	41.708	
Treatments	4	923.147	230.787	53.320 **
Experiment	4	8.631	2.153	1.217 N.S.
Interaction	16	69.253	4.328	2.447 *
Error	49	86.667	1.769	
Total	73	1087.680		

[a]Underlined values not different at 0.05 and 0.01 levels.

[b]Percentages given are for combined survival rates of five experiments.

[c]Because of zero readings, 1 was added to all values for computation of ss.